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METHANE DESORPTION OF BOREHOLE COAL SAMPLES FROM GREENHILLS MULTIPLE SEAMS

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METHANE DESORPTION OF BOREHOLE COAL SAMPLES FROM GREENHILLS MULTIPLE SEAMS

by

K.K. Feng*, K.C. Cheng** and R. Augsten†

ABSTRACT

Methane emission and the desorption characteristics of methane gas from vertical borehole coal samples of Greenhills multiple seams in the vicinity of Elkford, B.C. were measured. Three vertical boreholes at depths of 335, 380 and 395 m were drilled along the west wall of an active open pit mine and 44 core samples from various coal seams were obtained for desorption studies. The methane content for various coal seams was obtained for desorption studies. The methane content was found to increase significantly at depths greater than 200 m. A mathematical correlation using the adsorption equation and the properties of the coal has been used to predict methane content and these are compared with the measured values. The results are presented in three tables and illustrated with six figures.

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INTRODUCTION

The coalification of plant materials in the sedimentary rock produces different ranks of coal and gases of various composition. The gas mixtures are retained in coalbeds and rock strata under pressure. The gas content of a coalbed varies considerably depending on the rank of coal and the depth of overburden. The measured values of gas content in major North American coalbeds show from near zero to 24 cm^3 per gram of coal (1,2). A gas content of 2.5 to 9 cm^3/g is considered "gassy" and that of 9 cm^3/g or higher is considered "very gassy" for underground mining (3). Normally, the gas mixtures released from bituminous coal in Canada contain 90 to 98% methane and the rest is made up of CO_2, N_2, O_2, H_2, He and other hydrocarbons (4).

As mining progresses, methane is released from coalbeds and mixed with mine air. Ventilation is essential for controlling methane content in coal mines. Inadequate ventilation may cause gas accumulation in the mines and lead to a gas explosion. The explosive range of methane concentration in an atmosphere free from coal dust is between 5 and 15% with a maximal intensity of explosion at 9.5%. For mine safety regulations, most countries accept either 1 or 1.25% methane in general mine atmosphere as a maximum allowable concentration for coal mining (5,6).

It is necessary to measure the gas content of coalbeds as an integral part of the mining program, so that the mine methane output can be estimated and ventilation requirements can be determined. It was reported that generally the quantity of methane output from a mine per ton of coal produced is about 6 to 9 times higher than the measured methane content of coalbeds (7). This increase is due to the emission of methane from adjacent strata, gob areas and pillars.

Various degasification techniques have been tested and the results show that 20 to 80% of the coalbed gas can be effectively removed. Degasification prior to mining will reduce explosion hazards and ventilation cost, increase productivity and conserve coalbed gas (8).

MEASUREMENTS OF METHANE CONTENT BY DIRECT METHOD

TECHNICAL BACKGROUND

The direct method was originally developed by CERCHAR in France as a

technique to measure the methane emission of coalbed samples by desorption. CERCHAR's equipment was designed to study the gas desorption characteristics of coal samples taken at the face or within the coalbeds (9). Subsequently, the U.S. Bureau of Mines adopted the method and modified CERCHAR's equipment for measuring the coalbed gases from exploration core samples (2,7,10).

The test procedure of direct method is to enclose the coal sample in a sealed container and measure the volume of gas emission regularly until the gas increment is less than 0.05 $cm^3/g/day$. Generally, it takes from a few days to about two months to complete a desorption test for a core sample. The desorbed gas is measured each time by water displacement with an inverted graduated cylinder. In our test procedure, the graduated cylinder is replaced by a graduated burette and a levelling bulb for the measurement of desorbable gas. The details of the testing procedure has been reported (11).

The total gas content in a coalbed sample includes the lost gas (Q_1), desorbed gas (Q_2) and residual gas (Q_3). After a core sample is separated from a coal seam, the sample starts to give off gases before it is sealed in the container. The amount of gas lost during this time is called "lost gas", which can be estimated by a graphical method using the first two hour readings of the Q_2 measurements. The "desorbed gas" is the quantity of gas released and measured while the core sample is in the sealed container. The desorption test of Q_2 is stopped when the gas emission rate decreases to less than 0.05 $cm^3/g/day$ for several consecutive days. The sample is then removed from the desorption bottle and dried at room temperature before the final test for the "residual gases", which is the amount of gas liberated when the coal sample is reduced to a fine powder below 200 mesh.

COLLECTION OF COAL SAMPLES

All core samples used for desorption test were obtained from boreholes which are drilled vertically from surface to intersect the coalbeds. The borehole can be drilled to the top of coalbed and then cored. It is preferable that the core sample is about 6 cm in diameter for fitting into the desorption bottle and the amount of coal sample required for each test should be between 500 and 1000 g. Once the coal is cored, the core sample should be recovered without delay and placed in the sample bottle immediately to minimize the lost gas. All the bottles should be checked for leaks with 690 kPa (100 psi) air pressure before use. The O-ring seal on the bottle must be kept

clean when disengaging the lid. After the coal sample is sealed in the bottle, the desorption test for measuring Q_2 should be carried out as soon as possible, particularly the first reading.

MEASUREMENT OF DESORBED GAS (Q_2)

After sealing the coal sample in the bottle, the gas pressure builds up due to a continuous emission of methane gas from the sample. The increased amount of gas should be measured and then discarded periodically. The initial emission rate is normally high. The measurements should be taken at 10 to 15 minute intervals for the first two hours, and then once or twice per hour for the following 5-10 hour period depending on the desorption rate of the particular sample. One reading per day should be adequate if a daily increment is less than 200 cm^3. The desorption test for Q_2 may be terminated when the daily increases are less than 0.05 $cm^3/g/day$ for several days. The changes in ambient temperature and pressure must be recorded when readings are taken.

ESTIMATION OF LOST GAS (Q_1) BY GRAPHICAL METHOD

The methane is retained in coalbeds by the formation pressure. After coring, the coal sample starts to release the gas before it is placed in a desorption bottle. The amount of this unmeasurable "lost gas" is proportional to the time elapsed (called "lost gas" time) between the initial desorption time and the sealing time. The initial desorption time for a coal sample to start giving off gases is estimated and generally occurs when the gas pressure of the coal sample exceeds that of the hydrostatic head if water or mud is used as a cooling medium for drilling. At a normal drilling operation, it is assumed that the initial desorption time occurs at a mid-point between the coring time and the sealing time.

The "lost gas" of a coal sample can be determined by the graphical method, using the desorption data obtained from the "desorbed gas" (Q_2) measurements and corrected at standard temperature and pressure. Laboratory experiments (7,9) on methane desorption characteristics of coal samples, have indicated that the amount of desorbed gas is proportional to the square root of the desorption time, $Q_1 = K(t_1)^{0.5}$. It should be mentioned that in order to make this equation applicable, the desorption time intervals should be short and the partial pressure of methane should be low. A plotting of the

accumulative desorbed gas versus the square root of the desorption time will produce a straight line (Fig. 1). Generally, the straight line will pass through a point on the X axis equal to the square root of the "lost gas" time, t_o. By extrapolating back to zero time to intersect the Y axis, a negative quantity shown on the Y axis represents the amount of "lost gas" (Q_1). For example, the quantity Q_1 thus obtained from Fig. 1 for 657 g coal sample is

$$Q_1 = 250 \text{ cm}^3/657 \text{ g} = 0.380 \text{ cm}^3/\text{g at STP}$$

When plotting the data, one might realize that the points tend to deviate from the straight line as the desorption time increases. In order to obtain a better estimate of the "lost gas" quantity, it is important that:

(a) after coring, the sample should be recovered and placed in the desorption bottle as quickly as possible to minimize the "lost gas" time.

(b) after sealing the sample in the bottle, take the first reading as soon as possible. This is to prevent a high pressure buildup in the bottle that in turn will reduce the methane emission rate.

MEASUREMENT OF RESIDUAL GAS (Q_3)

When a solid core sample is used for the desorption test, the "residual gas" is liberated by breaking down the coal sample in two stages, to -10 mesh size by crushing, then to -200 mesh size by grinding. To estimate this residue gas, a portion of the coal sample approximately 2 to 5 cm in diameter is used to liberate the residual gas in a crushing apparatus. The sample is crushed to about 10 mesh in a confined chamber and the gas released is measured before the apparatus is opened. An example showing the calculation of residual gas (Q_c) released during crushing is given below.

Weight of sample = 24.5 g,
Residual gas released = 7.4 cm^3 at 1015 mb and 20°C,

$$Q_c = \frac{1015}{1013} \times \frac{273}{(273+20)} \times \frac{7.4}{24.5} = 0.282 \text{ cm}^3/\text{g at STP}$$

The gas released during grinding to 200 mesh is measured with the desorption apparatus before the vessel is opened. Nitrogen is used as the inert

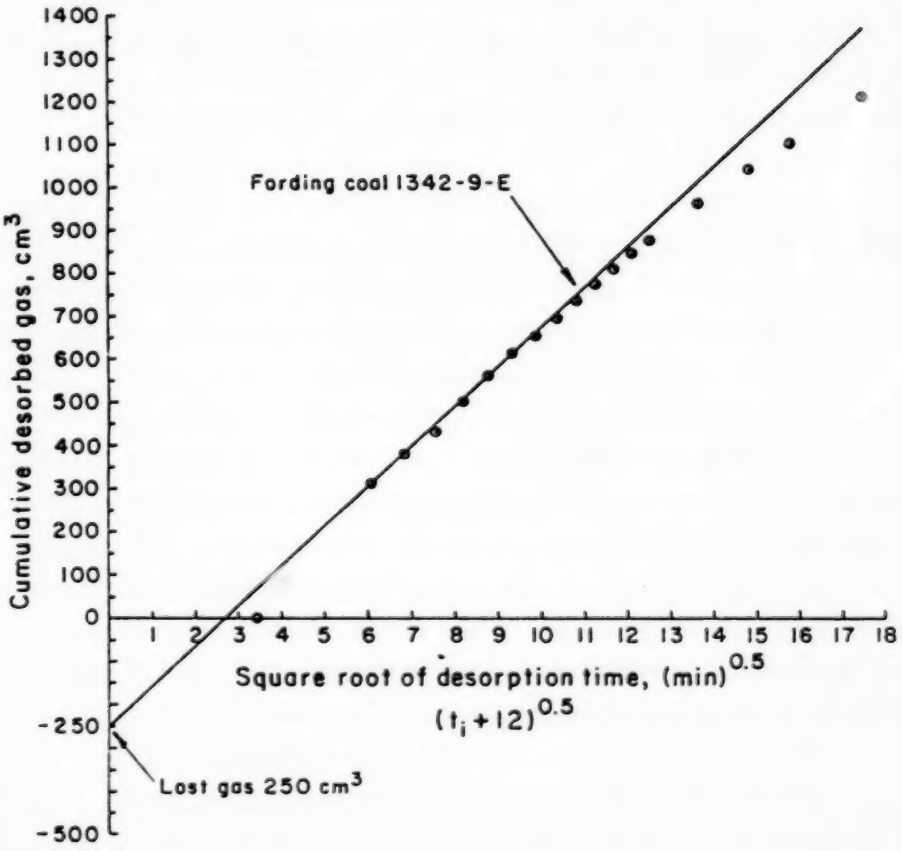

Fig. 1 - Lost gas curve for Fording Coal samples

gas in the ball mill during grinding. An example for the calculation of residual gas released during the grinding (Q_g) is given as follows:

Weight of sample = 538 g
Residual gas released = 1,041 cm^3
Ambient temperature = 20°C
Ambient pressure = 1015 mb
Ball mill internal temperature = 24°C

$$Q_g = \frac{1015}{1013} \times \frac{273}{(273+24)} \times \frac{1041}{538} = 1.782 \text{ cm}^3/\text{g at STP}$$

Hence, the total residual gas, $Q_3 = Q_c + Q_g = 0.282 + 1.782 = 2.064$ cm^3/g.

CALCULATION OF SPECIFIC GAS CONTENT OF COALBED SAMPLE

The total desorbed gas divided by the total sample weight represents a specific desorbed gas content of the coalbed sample in cm^3/g. The total specific gas content of the coalbed sample is:

Lost gas (Q_1) during first 12 min	0.380
Desorbed gas (Q_2) after 31.88 days	5.857
Residual gas (Q_3) after grinding to 200 mesh	2.064
Total gas (Q)	8.301 cm^3/g

By using a conversion factor of 32, this is equivalent to 265.6 ft^3 gas content per ton of coal in the coal seam.

ESTIMATION OF METHANE CONTENT WITH ANALYTICAL DATA

The adsorptive capacity of methane in coalbeds depends primarily on the in situ pressure, temperature and rank of coal. The amount of gas adsorbed by coal is directly proportional to pressure and inversely proportional to temperature. Since both the pressure and the temperature gradients in rock strata are functions of depth, the gas content of a coalbed can be directly related to the depth of overburden and the rank of coal. Also the rank is determined by the composition of coal samples such as the fixed carbon (F.C.),

volatile matter (V.M.), ash, moisture and oxygen contents. Therefore the gas content in coalbeds can be estimated with the general adsorption equation by Kim (12) as follows provided that the analytical data of coal samples are available:

$$Q = \frac{(100 - \%\text{moisture} - \%\text{ash})}{100} \cdot \frac{Q_w}{Q_d}(K(P)^{N_o} - bT)$$

where Q = volume of gas adsorbed in cm^3 per g of in situ coal sample

Q_w/Q_d = adsorptive factor depending on the ratio of wet coal to moisture-free coal sample, varying between 0.5 to 0.8 for most bituminous coal, $Q_w/Q_d = 1/(0.25 \times M + 1)$, M is the percentage of moisture in coal

K = adsorption constant due to pressure changes in $cm^3/g/atm$ depending on the composition of coal, $K = 0.8$ (F.C./V.M.) + 5.6 for most bituminous coal

N_o = constant depending on the composition of coal, $N_o = 0.39 - 0.013 \times K$ for most bituminous coal

P = pressure in atmospheres (atm), the average formation pressure in rock strata, $P = 0.063 \times h$ with h = depth in meters

b = adsorption constant due to temperature changes in $cm^3/g/°C$ with the value of the constant varying from 0.12 to 0.17 for most bituminous coal

T = temperature in Centigrade (°C), the formation temperature, $T = 0.027 \times h + T_o$ if the average geothermal gradient of 2.7°C per 100 m at Greenhills area is used (13). T_o is the annual mean air temperature

Using the pressure gradient of 0.063 atm/m, the temperature gradient of 0.027 °C/m and the mean air temperature of 4.5°C at Greenhills area (13), the gas content in Fording coalbeds can be estimated with the following equations.

(A) Desorption equation for Fording coal upper seams (F and above):

$$Q_{up} = 0.56\ (7.5(0.063 \times h)^{0.29} - 0.12(0.027 \times h + 4.5))$$

where

% moisture	= 1.9% (average value)
% ash	= 15.6% (average value)
F.C./V.M.	= 2.38% (average value)
Q_w/Q_d	= 1/(0.25 x 1.9 + 1) = 0.678
K = 0.8 x 2.38 + 5.6	= 7.50 $cm^3/g/atm$
N_o = 0.39 - 0.013 x 7.5	= 0.29
b	= 0.12 $cm^3/g/c$.

(B) Desorption equation for Fording coal lower seams (B to E):

$$Q_{lo} = 0.65(7.9(0.063 \times h)^{0.29} - 0.13(0.027 \times h + 4.5))$$

where

% moisture	= 1.1% (average value)
% ash	= 15.7% (average value)
F.C/V.M	= 2.85 (average value)
Q_w/Q_d	= 1/(0.25 x 1.1 + 1) = 0.784
K = 0.8 x 2.85 + 5.6	= 7.88 $cm^3/g/atm$
N_o = 0.39 - 0.013 x 7.88	= 0.288
b	= 0.13 $cm^3/g/c$

The gas content in the upper coal seams (F and above) and the lower coal seams (B to E) at various depths was calculated and the results were plotted in Fig. 6.

The calculated values by adsorption equations are considered to be accurate within $\pm$ 30% of the measured values by direct method (12). The main factors that cause such a high variation are the changes in coalbed moisture content, pressure gradient and geothermal gradient. Therefore field tests on these variables are necessary to justify the accuracy of this method.

RESULTS AND DISCUSSION

Three vertical boreholes (No. 1340, 1341 and 1342) were drilled at different locations along the west wall of the Greenhills open pit mine to depth of 335, 380 and 396 m respectively. The 6.0 cm core samples were cored

with a HQ core bit and a 1.524 m core barrel. A vertical cross-section showing the major Greenhills coal seams is illustrated in Fig. 2. A total of 44 core samples from various coalbeds was obtained from these boreholes for desorption tests and the results are summarized in Tables 1, 2 and 3. After the desorption tests, the samples were analyzed for their chemical compositions. Figures 3, 4 and 5 show characteristic desorption curves for various coal seams. Figure 6 shows the relationship between methane content and the depth of coalbeds and their correlation using various mathematical equations.

The major coal seams at the Greenhills area are medium-volatile bituminous coal. The methane content of Fording upper coal seams (H, G, F) ranges from 0.2 to 2.1 cm^3/g and that of the lower coal seams (B, C, D, E), 4.1 to 13.6 cm^3/g. The lower coal seams are considered as gassy coalbeds. The average methane content in B and E seams is 7.4 and 6.9 cm^3/g respectively. The coal samples from B seam are more friable than those from E seam. Figures 3 to 5 show that the initial methane emission rate of coal samples from B seam is about twice as much as that of samples from E seam. It indicates that the broken coal of B seam, as compared to that of E seam, will release more gas at the mining face and retain little gas as residual gas in the broken coal. The quality of coal samples from C and D seams is similar to that of E seam and the methane content in these coalbeds is comparable to those of B and E seams.

Figure 6 shows a plot of the gas content of each sample versus the depth of coalbeds. The result indicates that the methane content in coalbeds increases with the depth of overburden. The three curves obtained from fitting the data by means of a least squares technique are represented by A, B and C and are compared with the curves obtained using the desorption equations D and E. The desorption equations are derived using the analytical data of coal samples. Although none of them represents the data well, it appears that curve B is more suitable at lower depth, while curve A is more suitable at greater depth. The gas content was found to increase significantly at depths greater than 200 meters. It has been verified that at the Prince Mine, Sydney, N.S., that there was virtually no gas in the ventilating air at a depth 150 m. At a depth deeper than 150 m, an increase in methane emission was noticed (14).

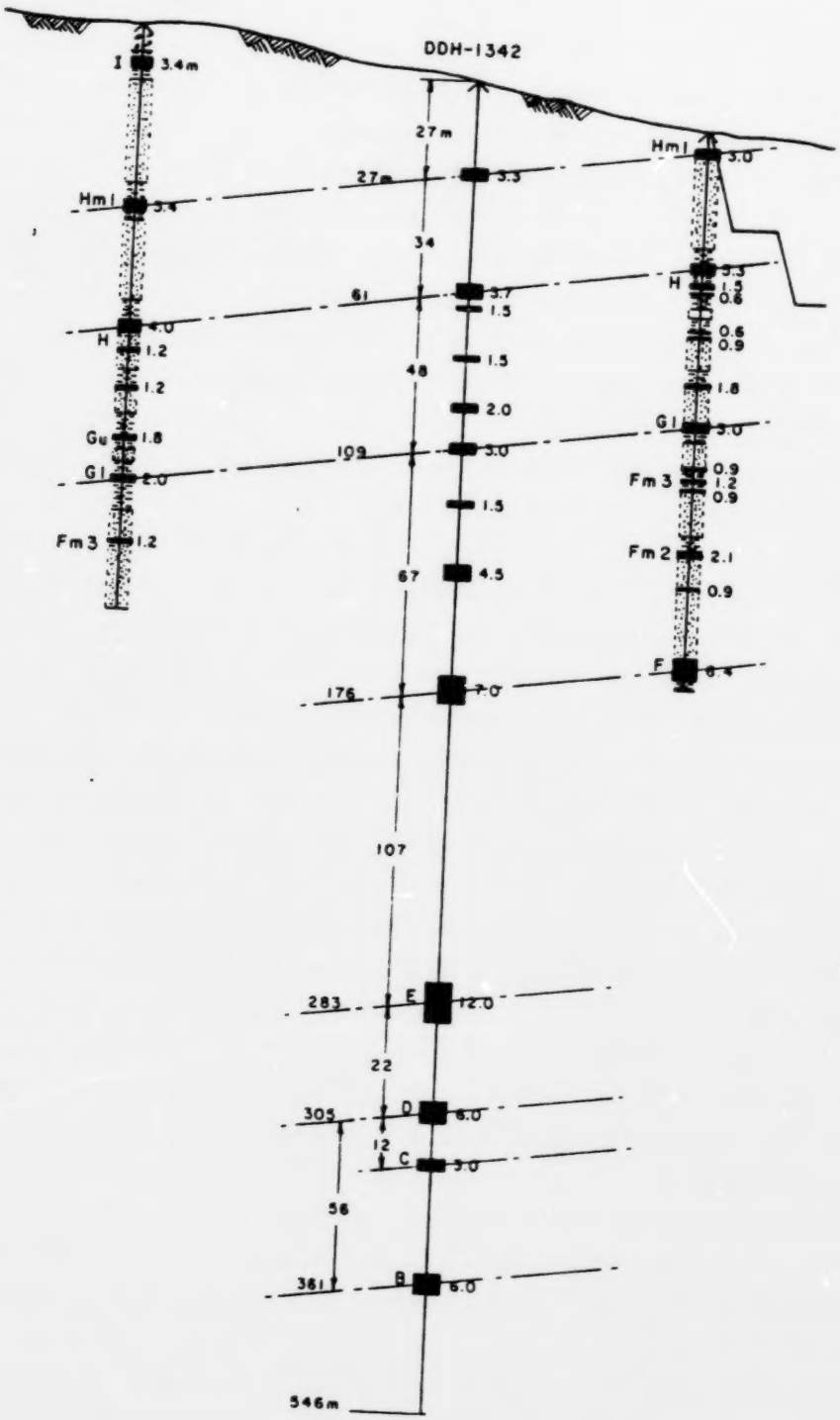

Fig. 2 - Vertical cross-section of Fording coalbeds at DDH-1342.

TABLE 1. Summary of Methane Desorption-Fording coal D.D.H. No.1340

Sample No.	Coal seam	Seam depth m	Core length m	Lost gas (Q_1) (cm^3/g)	Desorbed gas (Q_2) (cm^3/g)	Residual gas (Q_3) (cm^3/g)	Total Gas (Q) cm^3/g	Total Gas (Q) ft^3/ton	$\frac{Q_1}{Q}$ (%)	$\frac{Q_3}{Q}$ (%)
1	GU	39	1.5	0.055	0.379	1.080	1.514	48.5	3.6	71.3
2		84	1.5	0.046	0.470	0.735	1.249	40.0	3.5	58.8
3	F	102	0.6	0.050	0.525	0.696	1.271	40.7	3.9	54.8
4	F	119	0.9	0.191	0.754	0.347	1.292	41.3	14.8	26.9
5	F	120	2.4	0.087	0.536	1.446	2.069	66.2	4.2	69.9
6	F	122	1.5	0.059	0.490	1.011	1.500	48.0	3.9	67.4
7	E	218	1.2	0.165	1.679	2.253	4.098	131.1	4.0	55.0
8	E	230	1.5	0.321	2.618	2.589	5.528	176.9	5.8	46.8
9	E	231	1.5	0.260	3.769	3.060	7.089	226.8	3.7	43.2
10*	E	233	1.5	0.143	1.274	0.998	2.415	77.3	5.9	41.3
11	**	285	1.5	0.018	0.365	1.522	1.577	50.5	1.1	96.5
12	B	319	1.5	1.856	5.079	0.238	7.172	229.5	25.9	3.3
13	B	320	0.6	1.222	4.213	0.178	5.613	179.6	21.8	3.2

NOTE: *Sample at bottom of E seam with very high ash content.

**Seam could not be positively identified. It could be part of C seam

TABLE 2. Summary of Methane Desorption-Fording coal D.D.H. No.1341

Sample No.	Coal seam	Seam depth	Core length	Lost gas (Q_1)	Desorbed gas (Q_2)	Residual gas (Q_3)	Total Gas (Q)		$\frac{Q_1}{Q}$	$\frac{Q_3}{Q}$
		m	m	(cm^3/g)	(cm^3/g)	(cm^3/g)	cm^3/g	ft^3/ton	(%)	(%)
1	Hml	9	1.2	0.061	0.154		0.215	6.9		
2	H	43	--	0.062	0.270	0.640	0.972	31.1	6.4	65.8
3	H	44	—	0.052	0.213	0.575	0.840	26.9	6.2	68.5
4	Hl	47	—	0.059	0.138	0.658	0.855	27.3	6.9	77.0
5	F	157	1.5	0.075	0.452	0.807	1.334	42.7	5.6	60.5
6	F	158	1.5	0.049	0.243	0.329	0.621	19.9	7.9	53.0
7	E	249	1.4	0.672	4.466	1.562	6.700	214.4	10.0	23.3
8	E	252	1.5	0.913	5.920	1.264	8.097	259.1	11.3	15.6
9	E	255	1.5	1.009	5.840	0.436	7.285	233.1	13.8	6.0
10	E	259	1.5	0.429	5.362	2.235	8.026	256.8	5.3	27.2
11	E	262	1.5	0.737	4.383	0.657	5.778	184.9	12.8	11.7
12	D	283	1.4	0.889	8.918	1.257	11.065	354.1	8.0	11.4
13	D	285	1.5	0.854	8.305	1.443	10.602	339.3	8.1	13.6
14	C	296	1.5	0.453	6.060	2.335	8.850	283.2	5.1	26.0
15	B	343	1.5	1.124	4.889	0.430	6.443	206.2	17.4	6.7
16	B	344	1.2	1.153	4.853	0.141	6.147	196.7	18.8	2.3

TABLE 3. Summary of Methane Desorption-Fording coal D.D.H. No.1342

Sample No.	Coal seam	Seam depth m	Core length m	Lost gas (Q_1) (cm^3/g)	Desorbed gas (Q_2) (cm^3/g)	Residual gas (Q_3) (cm^3/g)	Total Gas (Q) cm^3/g	Total Gas (Q) ft^3/ton	$\frac{Q_1}{Q}$ (%)	$\frac{Q_3}{Q}$ (%)
1	Hml	27	1.5	0.017	0.064	0.132	0.213	6.8	8.0	62.3
2	H	61		0.024	0.245	0.638	0.907	9.0	2.6	70.3
3	Gl	109	1.2	0.090	0.540	0.773	1.404	44.9	6.4	55.1
4	F	175	1.2	0.065	0.519	0.215	0.799	25.6	8.1	27.0
5	F	177	1.5	0.090	0.887	0.576	1.554	49.7	5.8	37.1
6	E	280	1.2	1.150	4.694	0.437	6.281	201.0	18.3	7.0
7	E	282	1.5	1.044	4.354	2.214	7.612	243.6	13.7	29.1
8	E	285	1.5	0.495	4.888	2.586	7.969	255.0	6.2	32.5
9	E	287	1.5	0.502	5.729	2.064	8.295	265.4	6.1	24.9
10	D	302	1.5	0.705	3.695	1.326	5.726	183.2	12.3	23.2
11	D	303	1.5	2.215	9.878	1.453	13.546	433.5	16.4	10.7
12	D	308	1.5	0.568	6.372	2.728	9.668	309.4	5.9	28.2
13	B	357	1.5	1.864	5.580	0.206	7.650	244.8	24.4	2.7
14	B	358	1.5	1.810	6.743	0.382	8.935	285.9	20.3	4.3
15	B	364	1.5	1.983	7.024	0.931	9.938	318.0	19.9	9.4

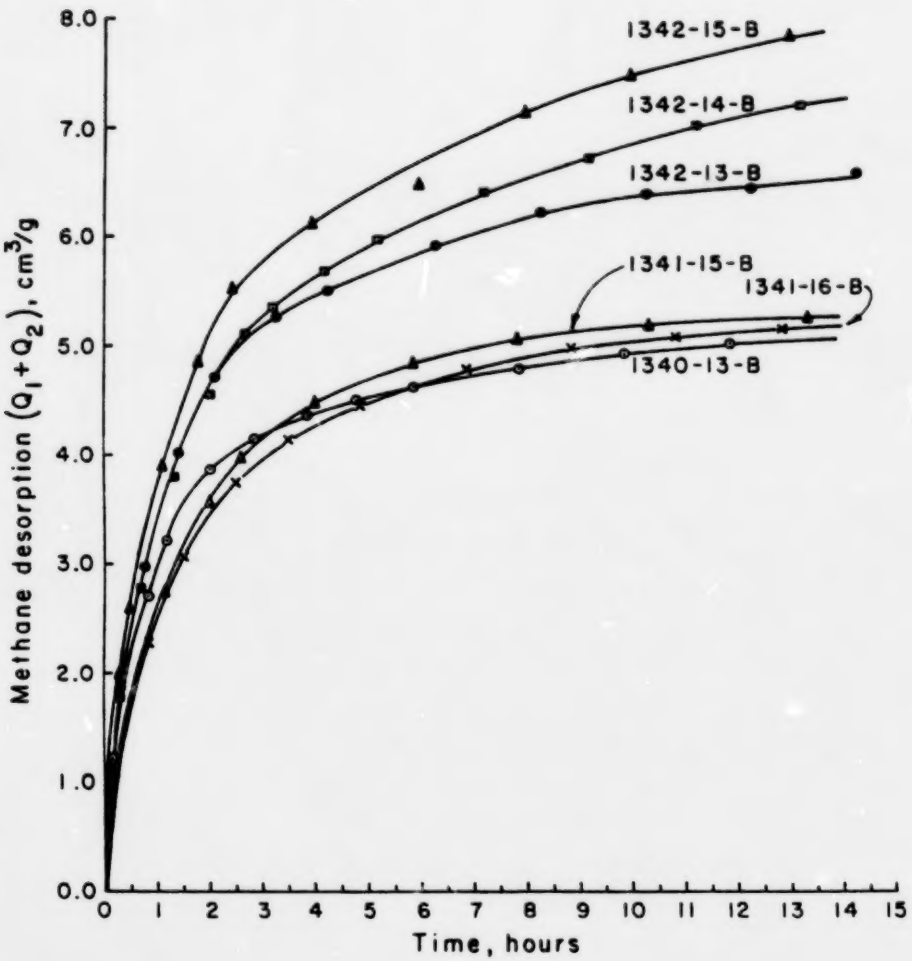

Fig. 3 - Methane desorption rate of core samples
- Fording Coal "B" Seam

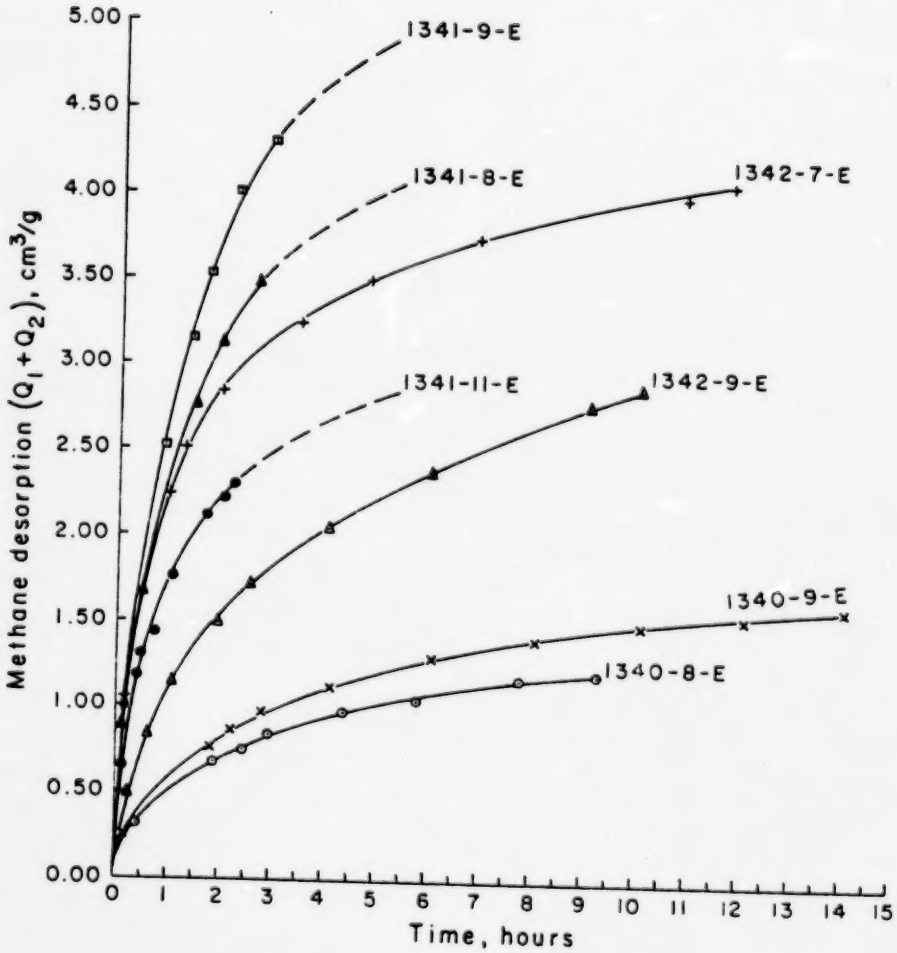

Fig. 4 - Methane desorption rate of core samples-Fording Coal "E" Seam.

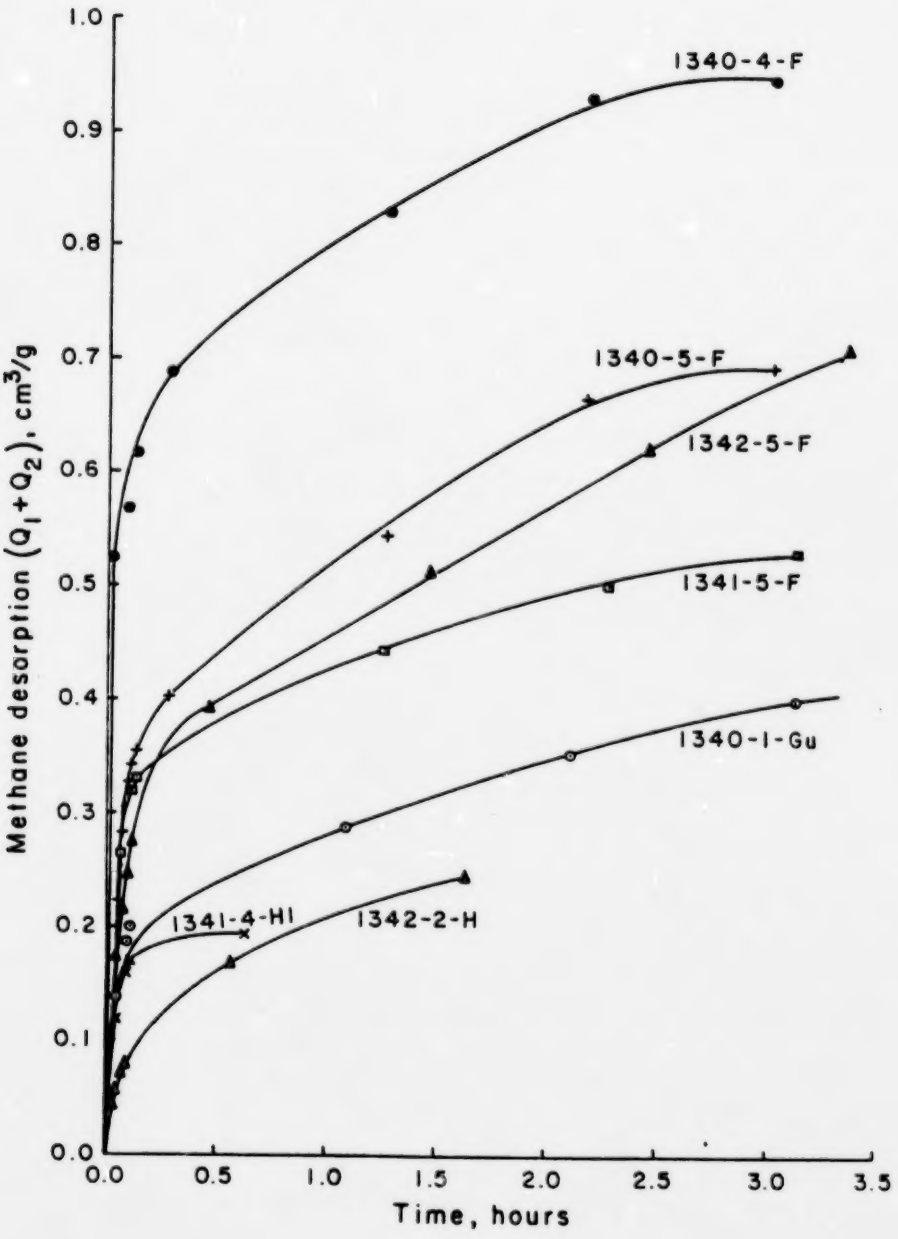

Fig. 5 - Methane desorption rate of core samples-Fording Coal Upper Seams.

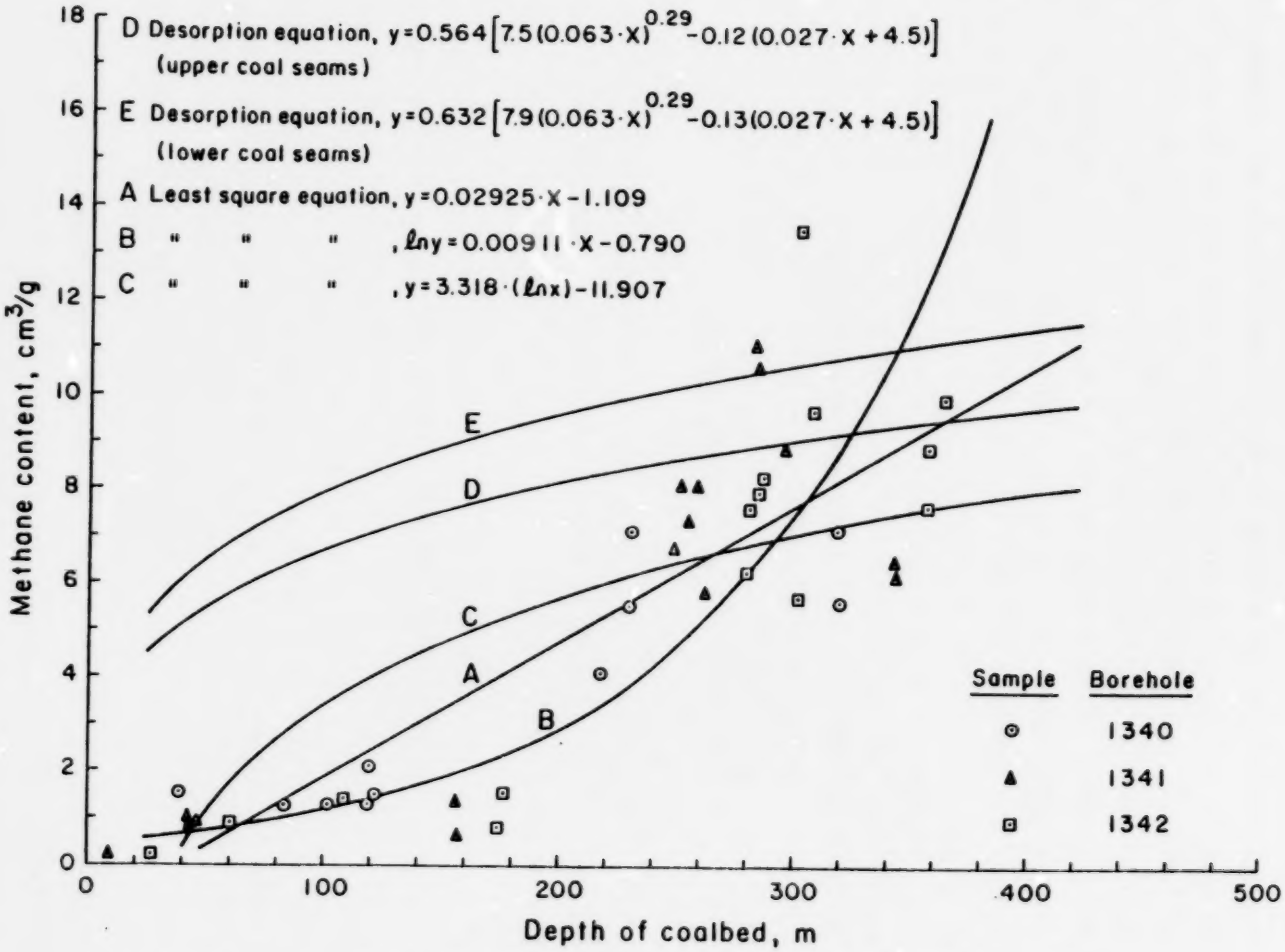

Fig. 6 - Methane content of Fording coals versus depth of coalbeds.

CONCLUSIONS

The methane content in Fording coalbeds increases with the depth of overburden. At depths less than 200 m, the total gas content is less than one quarter of that at a depth of 400 m. It appeared that gas emission has already taken place at a depth of 200 m as confirmed by the high percentage of residual gas in the total gas content. The average gas content as a function of depth as expressed by the equation $\ln Q = (0.00911 \times \text{depth} - 0.790)$ cm^3/g is valid up to a depth of 400 m with a correlation coefficient of 0.88 and a standard error of 1.09 cm^3/g. The correlation between methane content in coal and depth of the coal seam is considered fair and more tests may improve the precision of the result.

The rank of major coal seams at Greenhills area is medium-volatile bituminous coal and the coalbeds more than 200 m in depth are considered gassy. The coal samples from B seam are most friable and have high ratios of F.C./V.M. and high methane emission rate.

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